Microreflectors for Mars, Phobos/Deimos and Asteroids/Comets

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SCF_Lab
Satellite/Lunar/GNSS
laser ranging/altimetry and Cube/microsat
Characterization Facilities Laboratory

Scientific activities @ the SCF_Lab

- **Lunar Laser Ranging (LLR)** (See **Luca Porcelli**'s talk on Thursday afternoon)
  MoonLIGHT (**Moon** **L**aser **I**nstrumentation for **G**eneral relativity **H**igh-accuracy **T**ests).

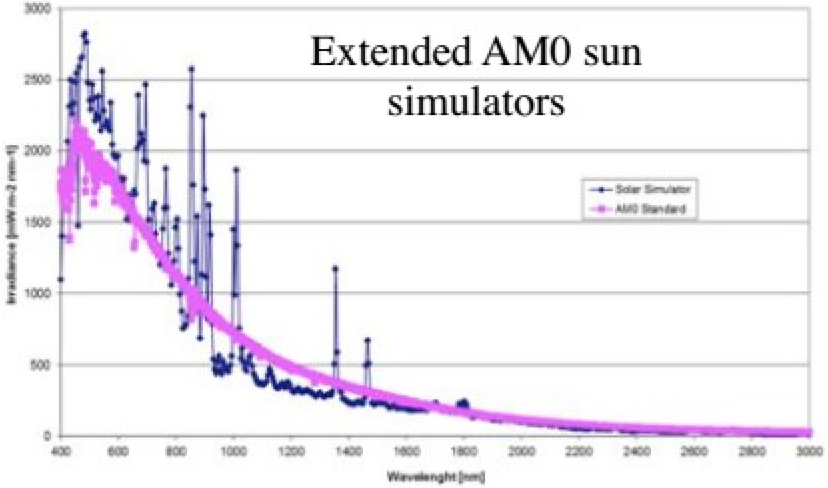
- **Satellite Laser Ranging (SLR)** (**Chiara Mondaini**'s talk of Wednesday morning)
  Arrays of retroreflectors for: Galileo IOV (**I**n **O**rbit **V**alidation), IRNSS (**I**ndian **R**egional **N**avigation **S**atellite **S**ystem), LAGEOS, GRA (**GNSS** **R**etroreflector **A**rray).

- **Microreflector arrays in the Solar System**
  - ***On the Moon:*** INRRI (**IN**strument for landing-**R**oving laser **R**etroreflector **I**nvestigations), to be observed by laser equipped lunar orbiters.
  - ***On Mars:*** INRRI on ExoMars 2016 (ESA), LaRRI (**La**ser **R**etro-**R**eflector for **I**nSight) on the InSight lander, landing on Mars on November 26, 2018 (NASA), LaRA (**La**ser **R**etro-reflector **A**rray) on Mars 2020 Rover (NASA).
  - ***On Phobos/Deimos:*** PANDORA (**P**hobos **AN**d **D**eim**O**s **R**etroreflector **A**rray) onto Mars' moons to be observed from laser-equipped satellites orbiting around Mars.
  - ***On Asteroids/Comets:*** COSPHERA (**CO**met/asteroid **SPHE**rical **R**etroreflector **A**rray) landed/dropped on asteroid or comet to support laser tracking by orbiters, laser altimetry capabilities (like Hera), or lasercomm payloads.

- **PEP (Planetary Ephemeris Program) & GR (General Relativity) tests**
  Developed at the Harvard-Smithsonian Center for Astrophysics **(CfA)**, USA, by Shapiro, Reasenberg, Chandler since 1960s. Lunar/Martian positioning data to perform test of GR up to 1.5 AU

SCF_Lab (Satellite/lunar/GNSS laser ranging/altimetry and Cube/microsat Characterization Facilities Laboratory)

- Specialized Optical Ground Support Equipment
- Optical tests: Far Field Diffraction Pattern, Fizeau interferometry
- Representative space environments for TRL (**T**echnology **R**eadiness **L**evel) 6-7
- SCF (left) for laser ranging and altimetry & SCF-G (right) optimized for GNSS
- Two AM0 sun simulators, IR thermometry
- *J. Adv. Space Res. 47 (2011) 822–842*

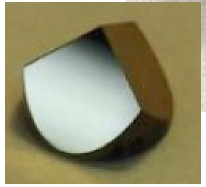


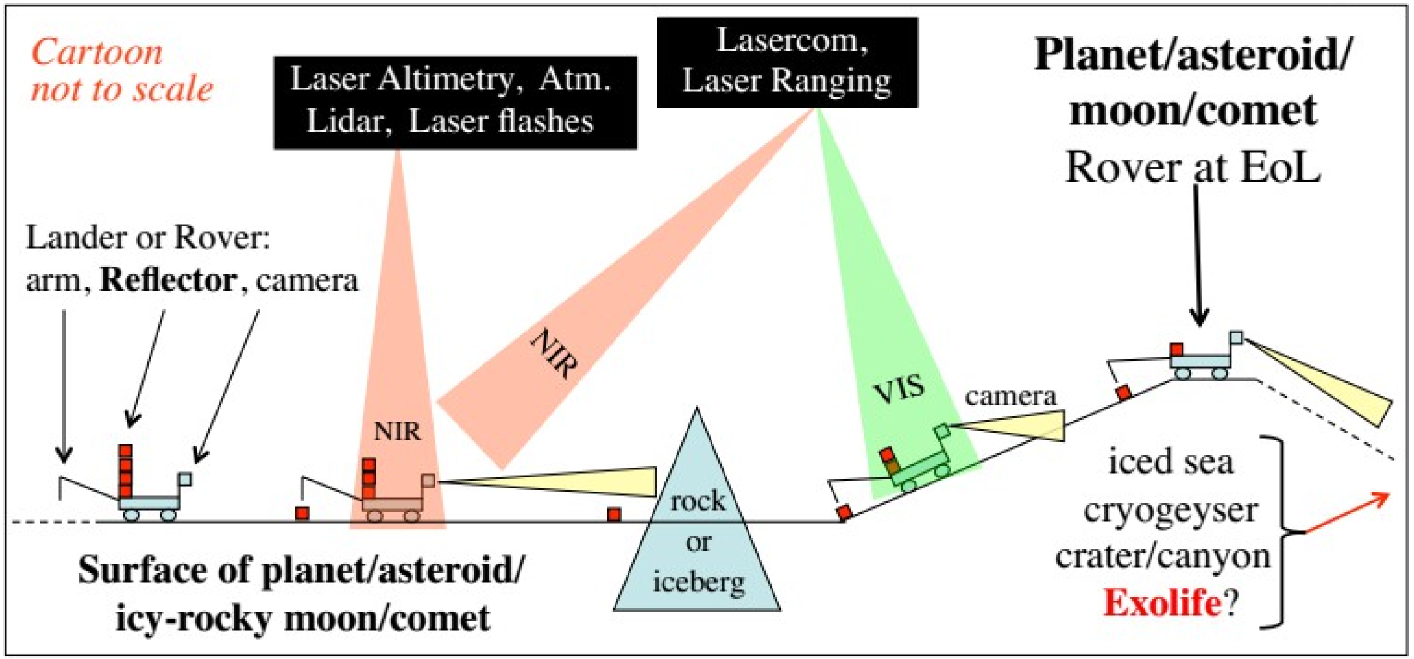
On Mars: INRRI, LaRRI & LaRA

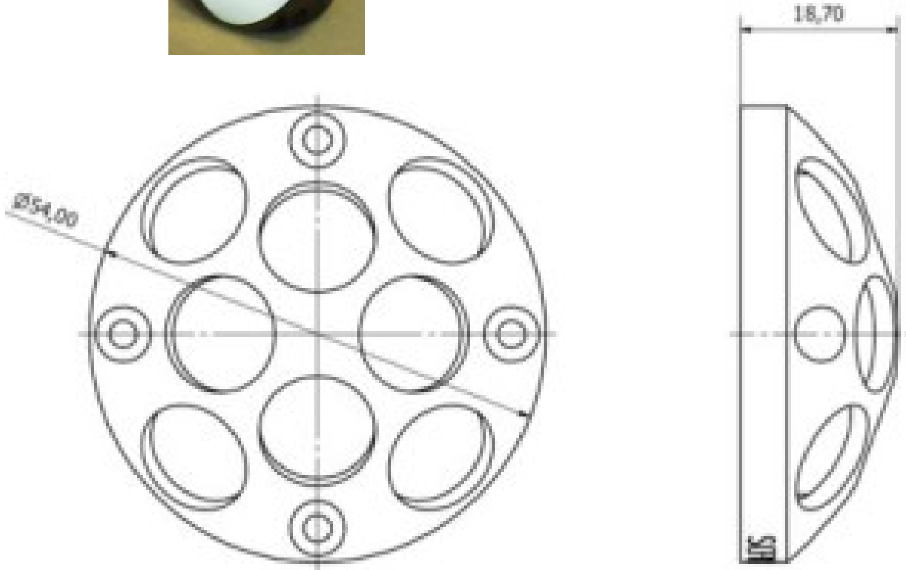
- Array: 8 silver/Al coated 12.7mm CCRs, physical edges to the center of a sphere;
- Frame: aluminium alloy;
- Weight and size: 25 g for 5cm of radius and 2cm of height.

Goals

- Laser-location of lander/rovers on Moon/Mars/asteroids/comets from orbiters;
- Global and local networks for Exploration, Planetary Science, Geodesy and test Fundamental Gravity.



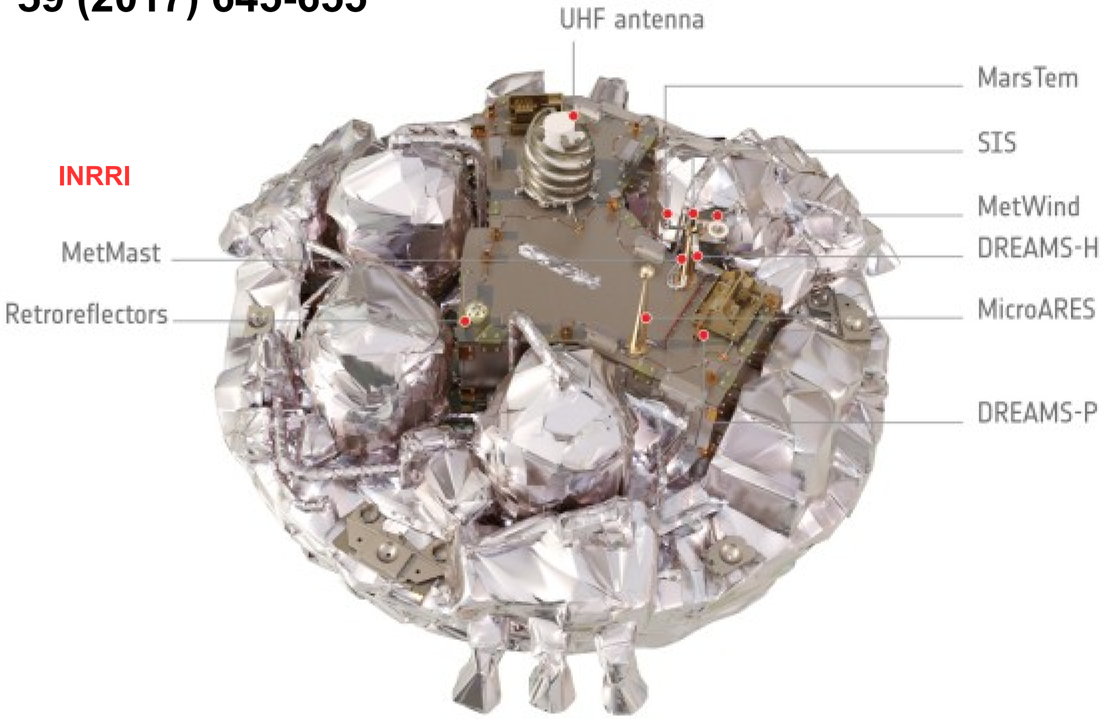




INRRI

The 1st microretroreflector on Mars on the lander Schiaparelli of ExoMars 2016

"*INRRI-EDM/2016: the first laser retroreflector on the surface of Mars*", Dell'Agnello et al., Adv. Space Res. 59 (2017) 645-655

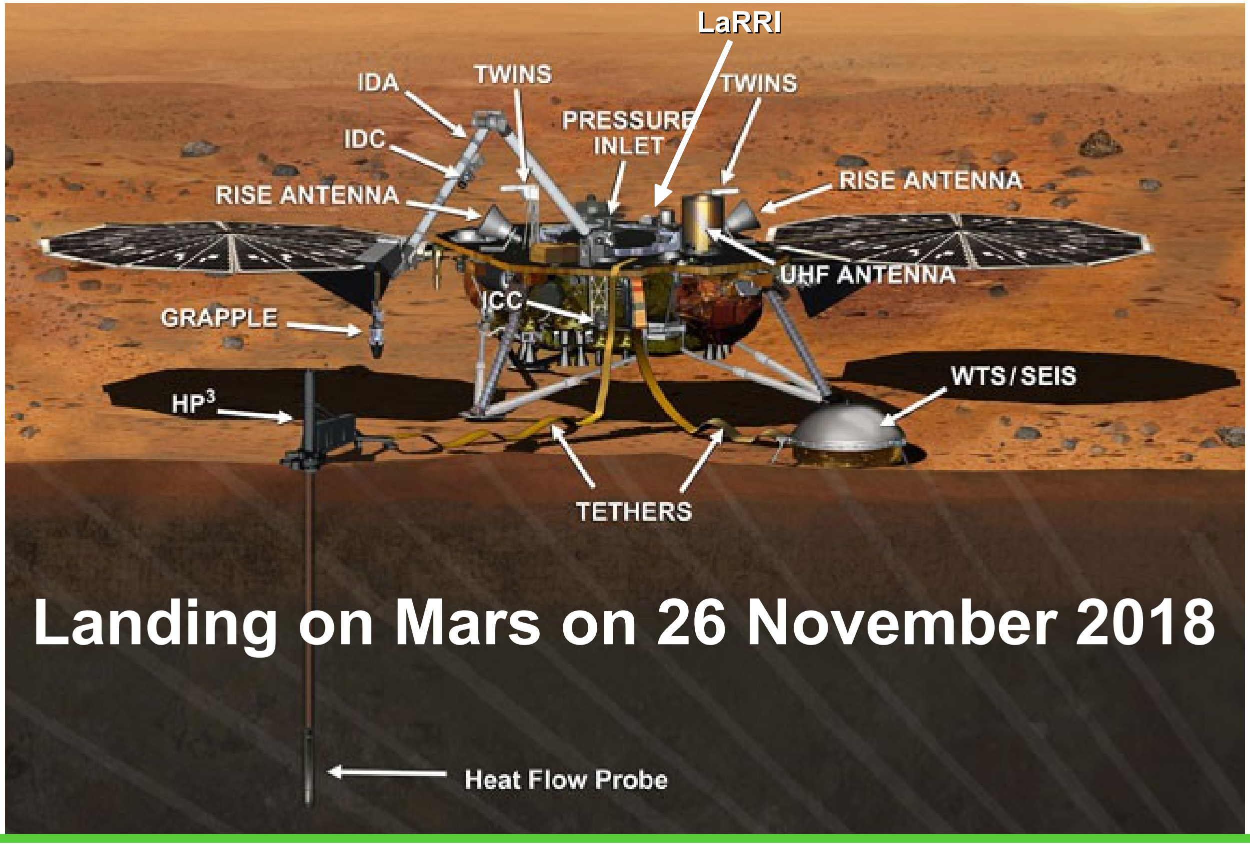


LaRRI

The 2nd microreflector on board InSight Mars Lander

Optical performance test, in-air & isothermal conditions

Paper 1: "*LaRRI: Laser Retro-Reflector for InSight Mars Lander*", Dell'Agnello et al., Space Res. Today 200 (2017)



LaRRI space qualifications (paper 1)

- Bakeout: T= (370±1)K = (96.85±1)°C for >48hr;
- Passed four TVT cycles: min/max $\Longrightarrow$ (363±1)K / (138±1)K = (89,85±1)°C / (-135.15±1)°C
- Passed dynamic loads qualification
- Passed Contamination Control requirements
- Passed Planetary Protection requirements (jointly with Mars 2020)
- Passed load-peel test of reflector glueing before/after TVT & dynamic loads
- Passed mass-loss check before/after TVT & dynamic loads

LaRRI Optical performance test (paper 2)

- Tests in atmospheric/thermal conditions similar to those on Mars surface (except for dust storms):
  1) In-air test without solar simulator, changing LaRRI's bulk temp over wide range;
  2) In-air test with solar simulator (in excess of solar constant at Mars).

- Measurements:
  1) IR reflector temperature and thermal relaxation time (non invasive mesurement);
  2) **Full array optical response** at varying laser angles incident on LaRRI.

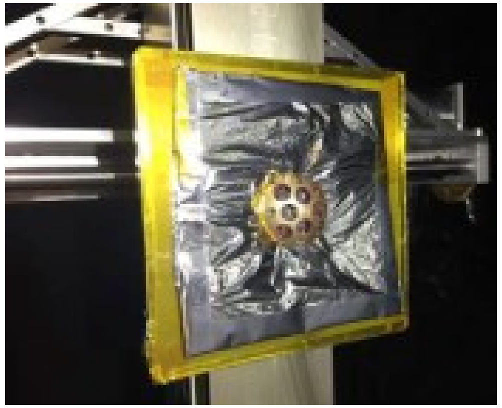
Paper 2: performance test without Solar Simulator

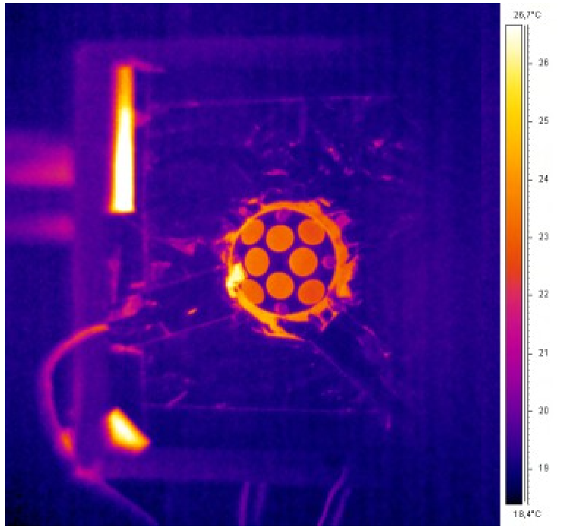
LaRRI instrumented with heaters and temperature probes. Thermally decoupled through thermal blanket from an especially designed baseplate. No vacuum was pulled.

– LaRRI bulk temperature: 20–70°C in 10°C steps;

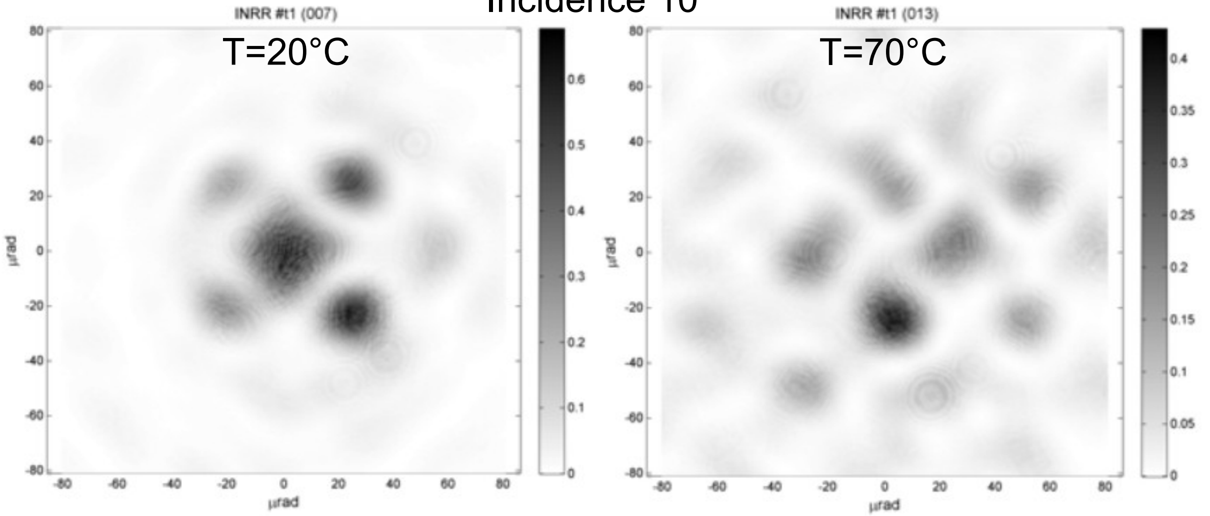
– Optical performances: 0°–30° laser incidence.

Optical response preserved within factor ~2 with respect to ILRS & altimetry standards

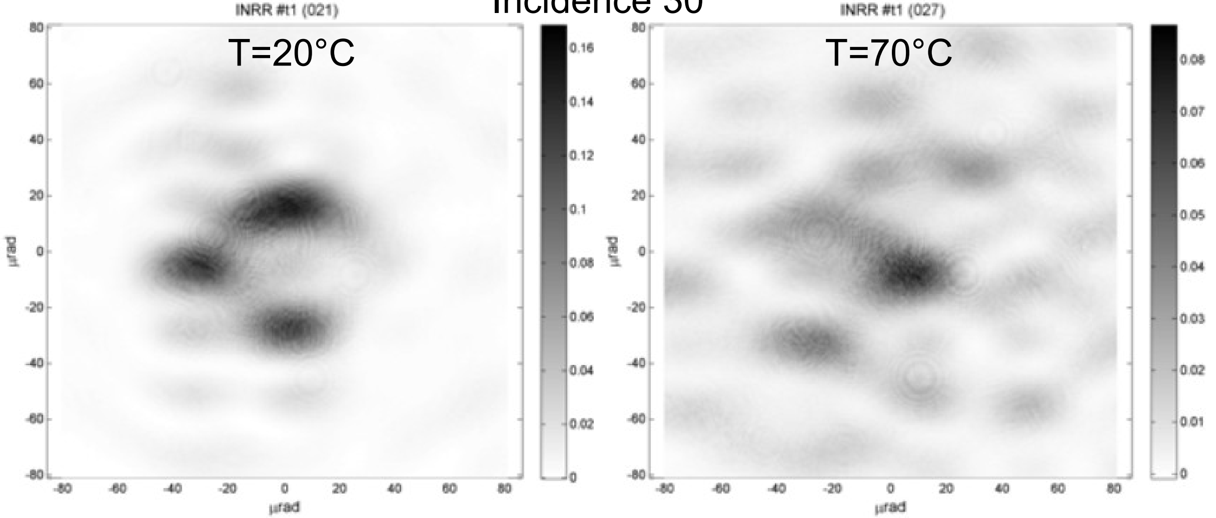




Incidence 10°



Incidence 30°

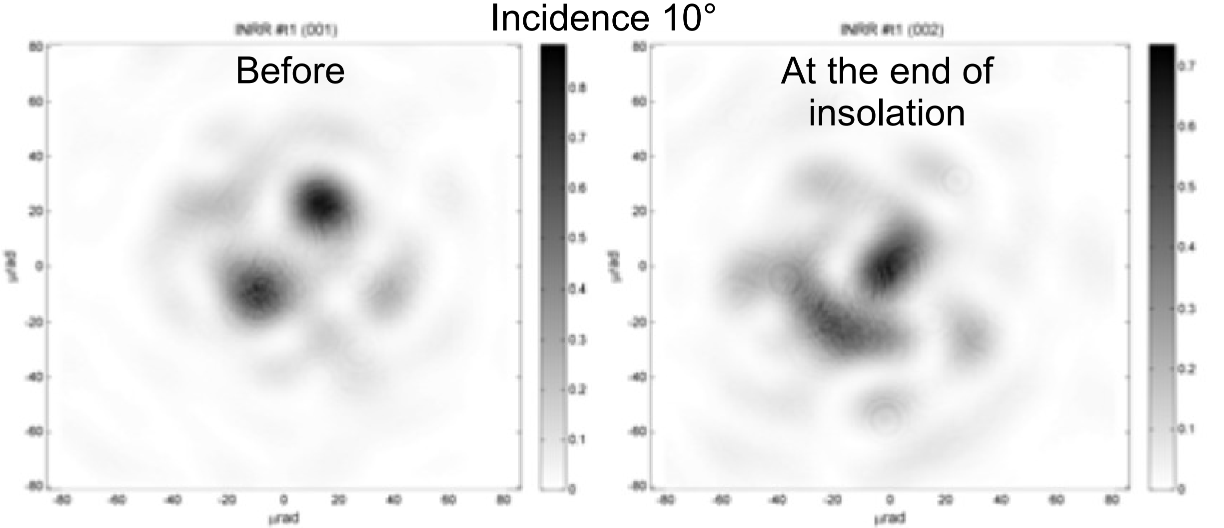


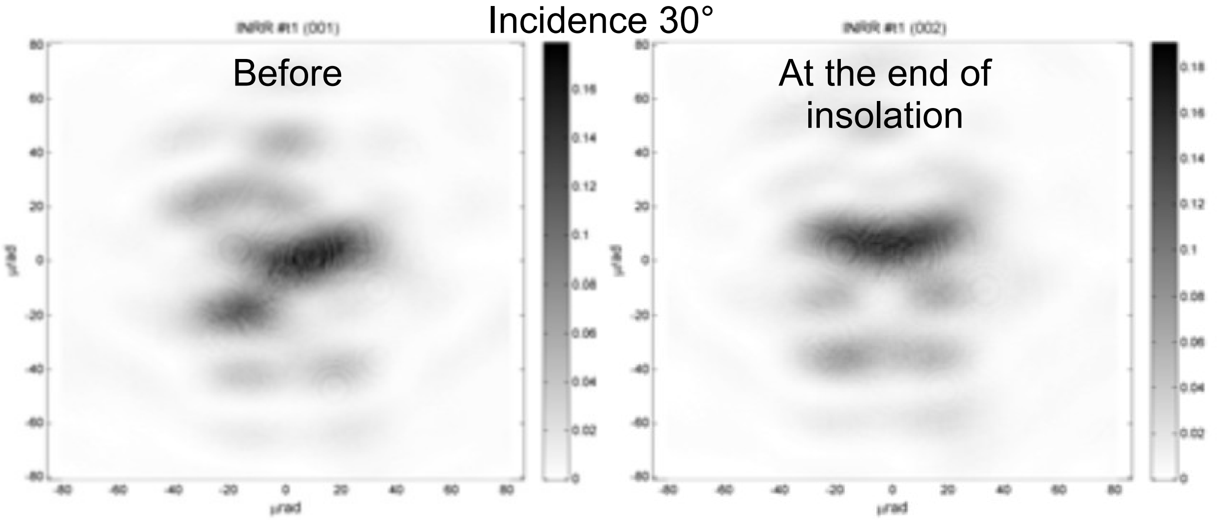
Paper 2: performance test with the Solar Simulator

More representative/realistic condition than previous.
Measurements (@solar constant higher by 50%):

- IR thermometry, thermal relaxation time τ (sec)
- Optical performance at varying incidence angles

Shape of laser return varies. Optical response preserved with an overall intensity unchanged at < 20% level with respect to the nominal





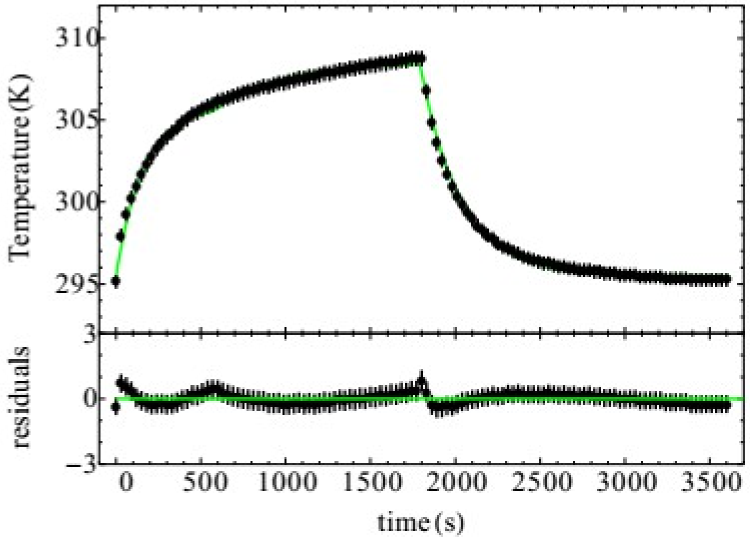


Table 1: τ of LaRRI

Angle [°]	τ [s]	σ_τ[s]
10	156	9
20	155	12
30	162	7

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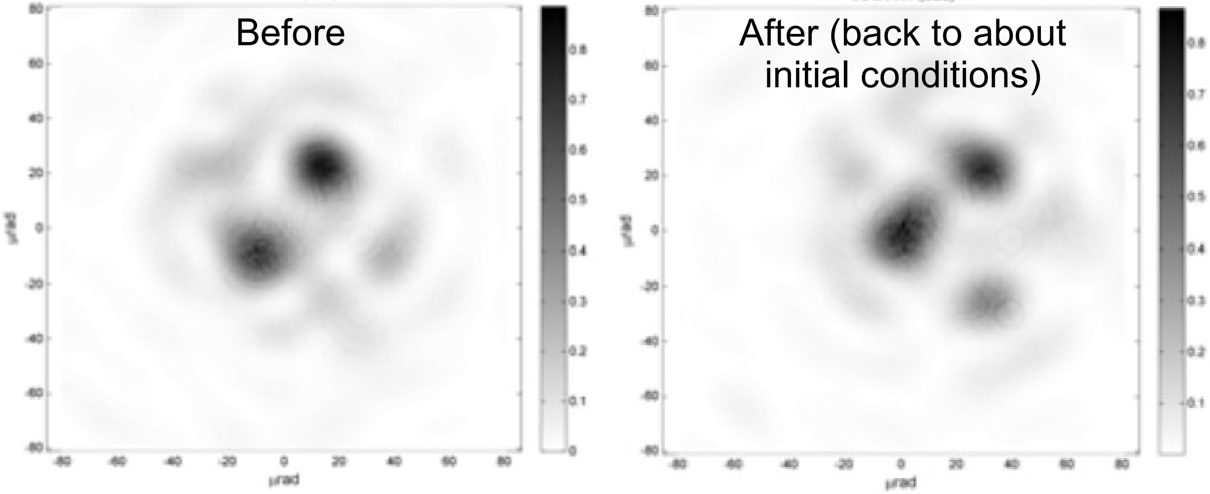

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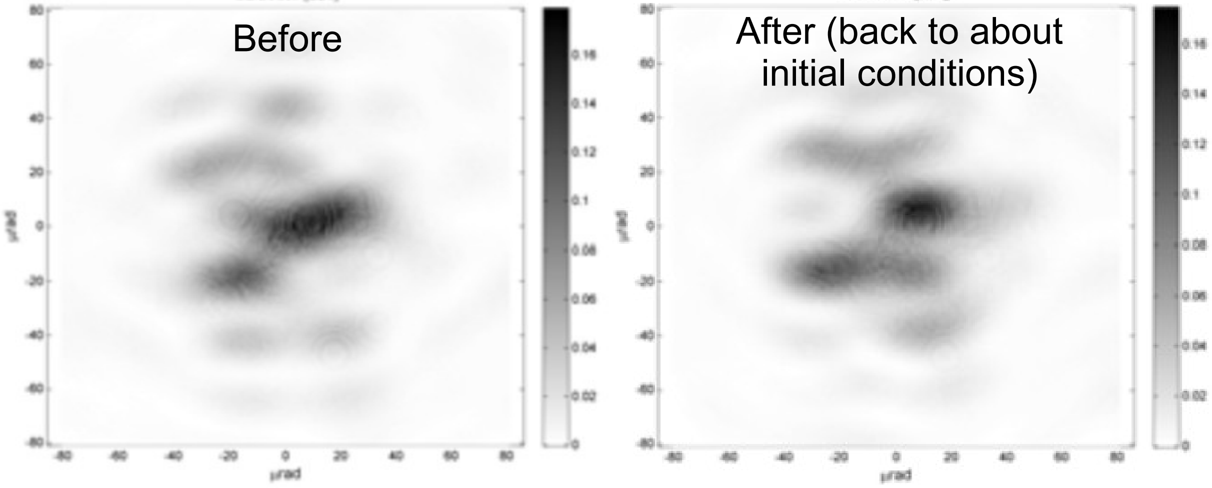

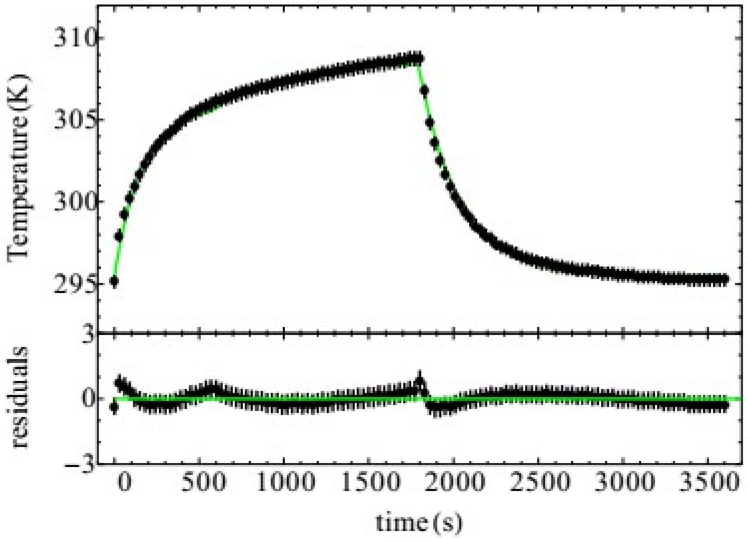

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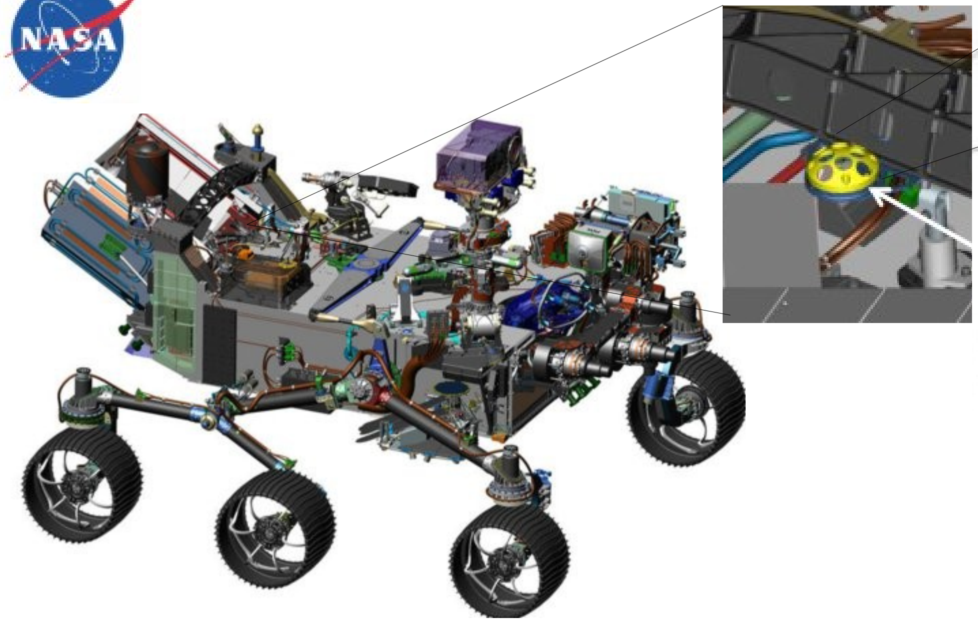
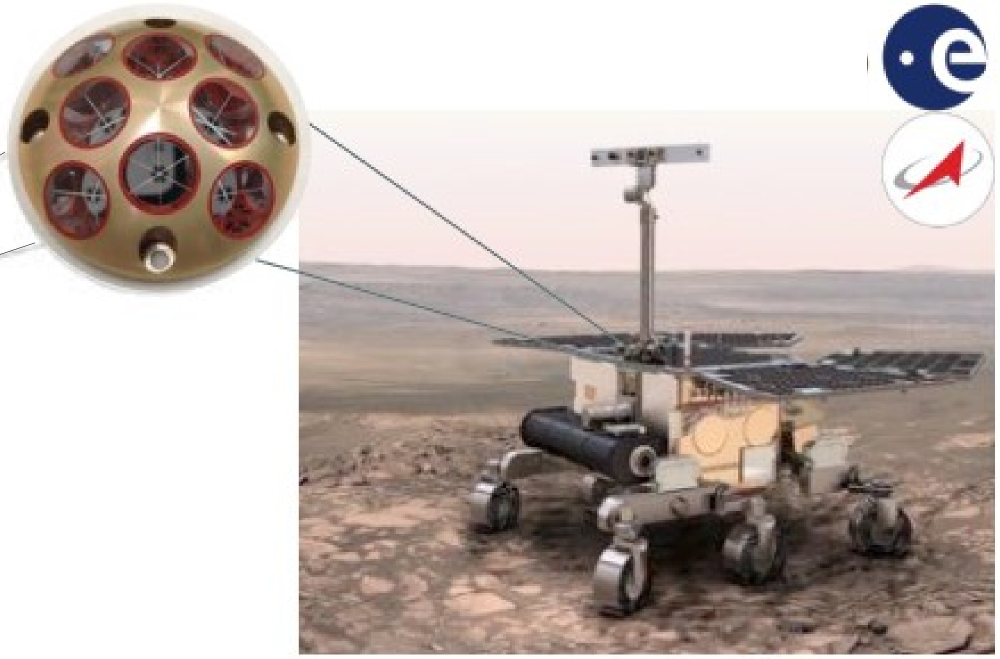
LaRA
Mars 2020 Rover
(NASA)

INRRI
ExoMars 2020 Rover
(ESA)

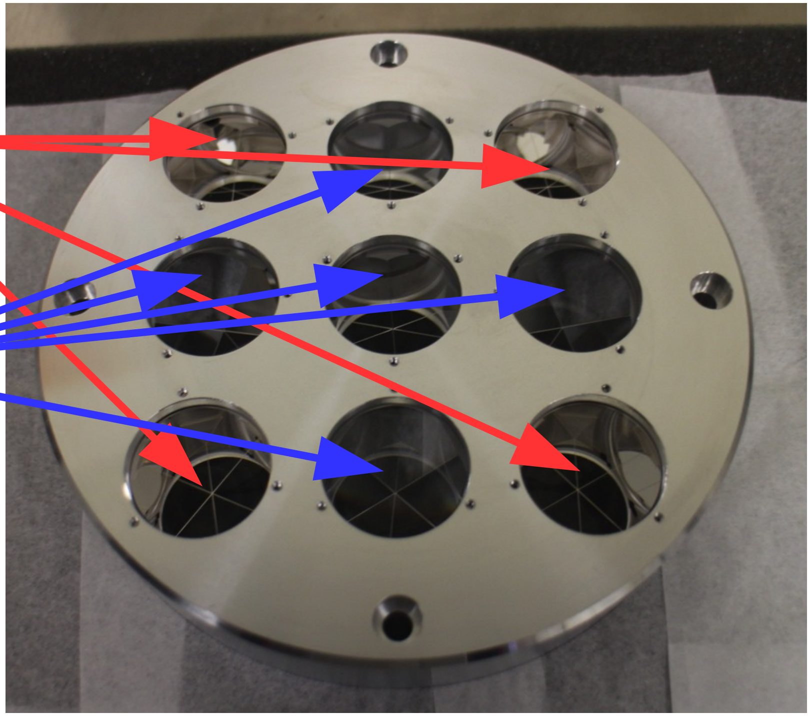


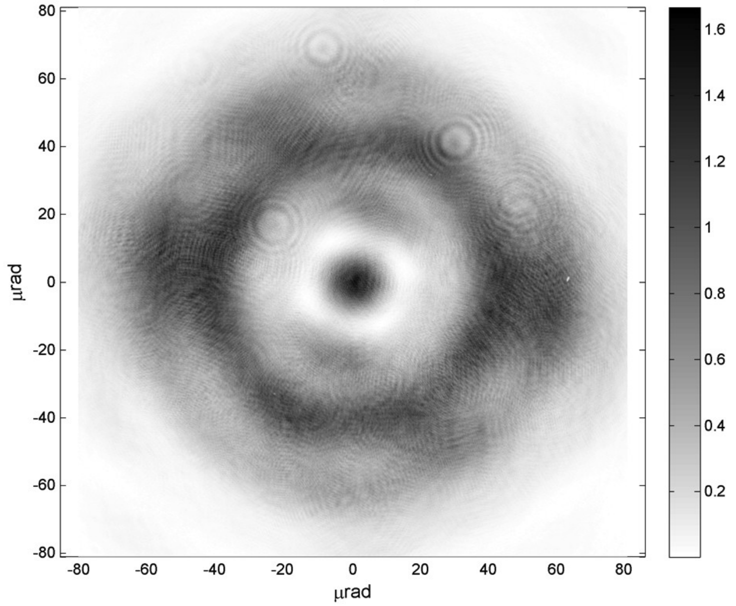


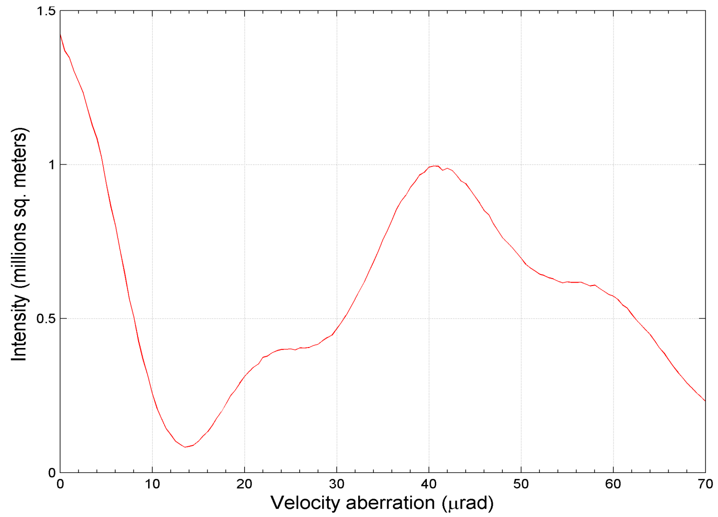
On Phobos/Deimos: PANDORA

- Array: 9 CCRs (d=33mm), optical design customized for Phobos/Deimos;
- Material: fused silica;
- Metal support body: Al 6000 series;
- CCR mounting elements: KEL-F PCTFE plastic;
- Total mass: < 1 kg.

4 CCRs for high VA (35-60 μrad)	
DAO:	3x(1.8±0.5)"
Material:	Suprasil 1
Coating:	Silver
5 CCRs for low-med VA (15-35 μrad)	
DAO:	3x(0.0±0.5)"
Material:	Suprasil 1
Coating:	None







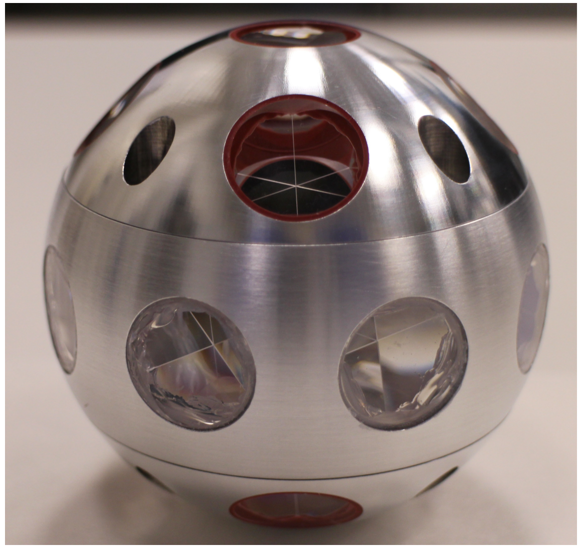
General Relativity Test with INRRI, LaRRI, LaRA & PANDORA

– Estimate Mars center of mass like Selenocenter with LGN;
– Mars center of mass and focii of Phobos/Deimos orbits;
– PPN γ, $\dot{G}/G$, $1/r^2$ law (Sun-Mars), PPN β (Sun-Mars-Jupiter)
(see Phobos laser ranging: S. Turyshev et al, arxiv:1003.4961v2 and references therein);

– Assume a MGN (Mars Geophysical Networks) of microreflectors (non-ideal) with PEP at 1.5 AU:
→ Phoenix (68N, 234E), Viking1 (22N, 50W), Viking 2 (48N, 258W), Curiosity (4S, 137E), Opportunity (2S, 354E);
– Assume data rate: 1 laser normal point (NP) every 7 Sols;
– Weather/operation limitations; visibility from orbiter like MRO is once/Sol;
– Accuracy: 10 cm-10 m (Mars ephemeris ~100-50 m);
– Earth-orbiter: radio ranging; future: laser à la LLCD or laser transponder experiments GGAO-MLA/MOLA.
Orbiter-surface: laser ranging/altimetry

Timespan/NP Accuracy	Accuracy on β-1	Accuracy on γ-1	Accuracy on $\dot{G}/G$
10 years/10 m	1.7xE-04	7.2xE-04	3.8xE-14
10 years/1 m	3.7xE-05	1.6xE-05	1.4xE-14
10 years/10 cm	7.4xE-07	3.2xE-06	2.9xE-15
Best accuracy now	1.0xE-04 LLR (JPL,CfA-INFN)	2.3xE-05 Cassini (Bertotti et al.)	9.0xE-13 LLR (JPL,CfA-INFN)

On Comets/Asteroids: COSPHERA



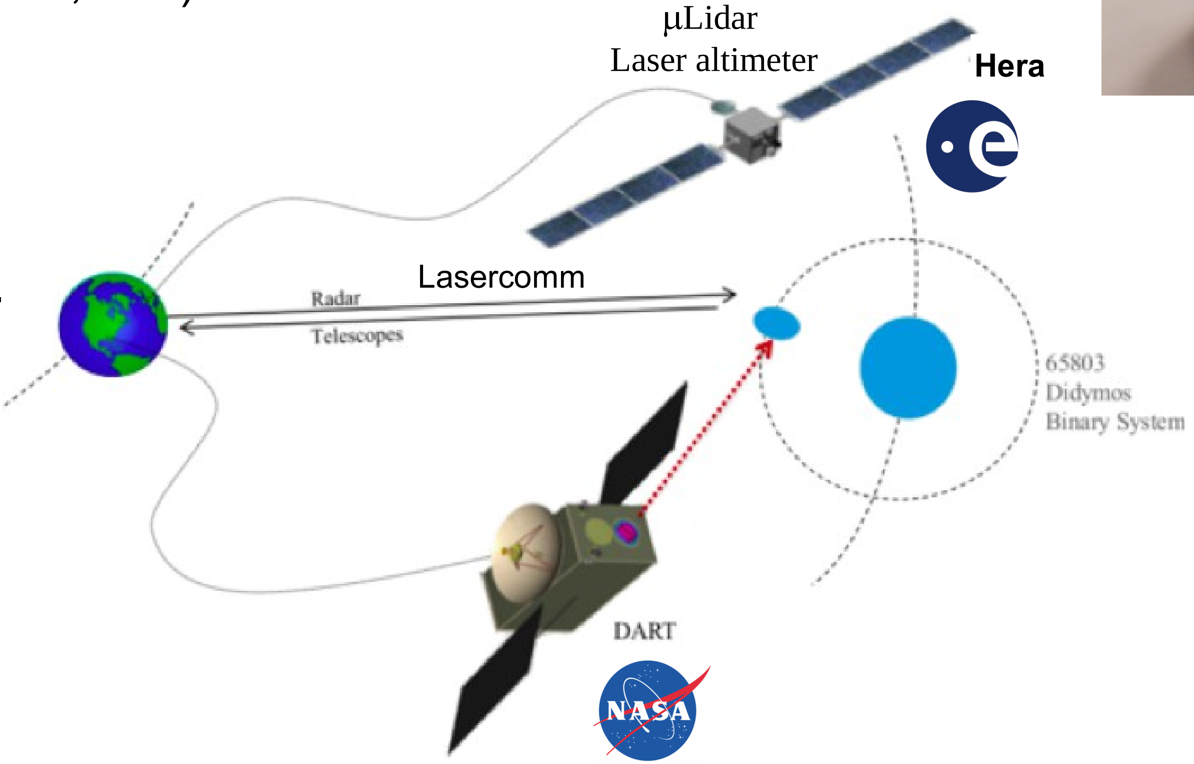
- Microreflector array: 18 CCRs of the same kind of INRRI, LaRRI, and LaRA on a sphere of Aluminium.
- To be dropped/landed on NEOs, as in missions like the ESA candidate **Hera**.
- Supports laser ranging by orbiters, laser altimetry, or lasercomm payloads performing ToF(**T**ime-**o**f-**F**light) laser ranging (like OPTEL-D foreseen for Hera, formerly the **A**steroid **I**mpact **M**ission, AIM)

Possible application:

Didymos double asteroid (1-2 AU).

Didymoon is the small secondary.

Hera has onboard μLidar, which a ToF laser altimeter



- Eccentricity: 0.384
- Inclination: 3.4 deg
- Geometric albedo: 0.147
- Diameter primary: 800 m
- Diameter secondary: 170 m
- Separation: 1100 m
- Orbital period secondary: 11.9 h
- Semi-major axis: 1.644 AU
- Orbital Period: 770.14 days

Conclusions and Outlooks

Mars space-qualified microreflector such as INRRI, LaRRI and LaRA will lead to:
– Mars Geophysical Networks (MGN)
– Accurate positioning of landing-roving
– Absolute mars-location of the rover site at end-of-life
– Lasercomm test & diagnostics.
– Atmospheric trace species detection by lidar on orbiter
– Lidar-based landing next to Mars 2020 for sample return

Phobos/Deimos microreflector together with INRRI, LaRRI and LaRA will lead to:
– Laser-ranging between Mars's moons and laser-equipped satellites orbing around Mars
– Enhanced tests of General Relativity at 1.5 AU

On Asteroids/Comets COSPHERA
– will be dropped/landed on NEOs, as in missions like the ESA candidate Hera.
– will supports laser ranging by orbiters, laser altimetry, performing ToF laser ranging (by the μLidar on board Hera)

Thank you!